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Abstract

Subject knowledge enhancement (SKE) is considered an essential part of initial teacher training (ITT) for secondary school roles. The article gives an insight into trainee teachers' different experiences and approaches they used to expand and acquire Physics and Mathematics subject knowledge, alongside other forms of knowledge. The unique feature of this article is that is written by four students in collaboration with their academic advisor. The trainee teachers joined the Physics with Maths Postgraduate Certificate in Education (PGCE) secondary course from varied backgrounds, with differing strengths. Therefore, they have enhanced their subject knowledge in different ways. Their reflections show how their subject knowledge has been synthesized from a range of previous experiences, subsequently developed in practice throughout the course, and how they develop their subject knowledge to the required level to begin their teaching careers in a confident manner.

Keywords: subject matter knowledge**,** subject knowledge enhancement (SKE); initial teacher training (ITT); reflection; secondary school; Physics; Mathematics; PGCE.

Introduction

The unique feature of this study is the focus on Physics and Mathematics subject knowledge experiences of four student teachers enrolled in a university PGCE course with Physics as the major subject component of their teaching in secondary schools. Three of these students had Physics (or Astrophysics) degrees; the fourth had studied engineering. Prior to joining the university initial training course, the trainee teachers held strong attitudes and beliefs about their subject knowledge developed during their education and working life. During this course, students attended regular Physics and Mathematics knowledge enhancement (SKE) university-based sessions, and students were also expected to carry out independent SKE during their school placements. This paper presents their reasons and strategies for engaging with and developing their subject knowledge. Although four students is obviously a small sample, it does serve to illustrate the different approaches and strategies they used to enhance their Physics and Mathematics knowledge.

Teachers' knowledge of subject matter

Defining subject matter knowledge is a complex task because the knowledge itself displays different facets and its significance may be very subtle. Subject matter knowledge is one of the facets of teachers' knowledge alongside the knowledge of curriculum and of students (Shulman, 1986). Shulman's seminal work on the pedagogical content knowledge (1987) underpins, alongside subject matter, the knowledge of planning, teaching, giving feedback and assessment. This suggests that subject knowledge is not exclusively used in the presentation of content, but it is deeply rooted in the foundations of personal practical knowledge (Connelly and Clandinin, 1997). The results from a longitudinal study, which was carried out over a 17 year period and based on a Physics concept (Arzi et al., 2008), show that changes in content knowledge are multifaceted for both beginning and experienced teachers. Therefore, the concept of content knowledge was expanded and broadened significantly over time. Angeli and Valanides (2009) argue that technology plays an important role in subject knowledge; therefore, the subject knowledge concept should be extended to include information technology.

Subject knowledge may appear to be of great importance, commonly being identified as one of the many attributes that make an outstanding teacher, and one of the most essential traits of a good teacher by pupils, but there is a limit to the effect it actually has on practice. Teachers with strong subject knowledge often provide more dynamic and interesting lessons than those who do not possess the same level of knowledge (McNamara, 1991). According to Hattie's meta-analyses of teaching influences, 'teacher subject matter knowledge' ranks 125 out of 138 influences that were ranked in terms of effectiveness of subject knowledge (Hattie, 2009:114). Its overall effect was positive, but not to a significant amount. Rice (2003) acknowledges that subject matter knowledge contributes to good teaching only up to a certain point, beyond which it does not seem to have an impact. Goodwin (2010) also claimed that possession of a higher degree (Masters, PhD) by the teacher has no discernible effect on their students' achievement.

Research has suggested that trainee teachers undertaking the employment-based route into teaching (Evans et al., 2008) encounter the biggest subject knowledge gaps. Nevertheless, even PGCE students with good degrees cannot be complacent about their subject knowledge for a number of reasons (Sperandeo-Mineo et al., 2006). For example, it may be some time since they obtained their degree; or their chosen field of teaching may require a broader knowledge than their degree specialisation. The National College for Teaching and Leadership (NCTL, 2015) funds SKE programmes courses, which have now been running for several years in subjects such as Mathematics and Physics. These courses are commonly set up by School Direct lead schools and ITT providers for trainee teachers, both prior to and during their training (Gibson et al., 2013), to help them to strengthen their subject knowledge.

At the time of writing this paper, relatively few published studies have reported the experiences of secondary Physics PGCE students in improving their subject knowledge (Sperandeo-Mineo at al., 2006). The study of Warburton (2013) looked at candidates taking Mathematics PGCE courses and found no correlation between attendance at SKE programmes and graduation grades. Gower and Capel (2004) share some common ground with this work, since it focusses on the SKE experiences of a group of PGCE students; however, all of the candidates were trainee physical education teachers. Ellis (2007) includes several reflective accounts of SKE experiences by trainee English PGCE students.

When a teachers have strong subject knowledge they are likely to include a variety of resources in their lessons, such as ICT and demonstrations, compared to a more didactic approach of a non-specialist covering the same material. McCarthy and Youens (2005) found that the use of textbooks and the support of their peers were the two most common SKE strategies used by students on one-year secondary PGCE. Burn et al. (2007) also highlighted the interaction with peers in school science departments as an important SKE strategy. Another interesting aspect of SKE is the potential difficulty which PGCE students experience in being open about their SKE deficiencies in front of their university tutors, since they are usually the same people who will assess those (Youens & McCarthy, 2007). These are just some of the aspects that will be explored in the following four reflective accounts.

Methodology

At the beginning of the Physics with Mathematics PGCE course, the university tutor initiated a researcher-to-students project to draw on students' reflections on their subject knowledge experiences and to find out if they had a 'unique practice' of teaching Physics, as they have to make it 'more learnable by their students' (Tiberghien's at al.,1998:6, Findlay et al, 2012). All the 2014/15 cohort of PGCE students participated in this project as they progressed through the PGCE courses. Due to the small number of students enrolled on this course, the study is limited by the size of the sample, only four participants. Therefore, any conclusions drawn are only applied within the context of this small group.

The inclusion of student teachers as co-writers and co-researchers provides opportunities for discussions of alternative interpretations of subject knowledge and

for the use of reflection as a research method. A collaborative web-based platform was set up on Google drive. In documenting our research, students were asked to do a literature search and choose a specified number of recent articles on subject knowledge for the annotated bibliography. The present paper was created using Google Docs and was shared amongst all co-authors. Regular feedback and review between trainee teachers and their university tutor helped them to write the reflective accounts, exchange ideas, give feedback on each other's work and develop higher-level awareness of their subject knowledge and critical analysis.

Reflective accounts

Each trainee teacher wrote one of the next four reflective accounts. The title of each entry has been chosen by them and reflects the key factors that are considered by them to play an important role on subject knowledge acquisition, alongside other forms of knowledge.

Student A - Previous experience teaching abroad being integrated into the PGCE course

My route onto the PGCE is not unique, but it gave me a different insight and focus whilst attending the course. Before commencing the PGCE, I spent 3 years teaching secondary Physics at an International School. This meant that my focus during the PGCE course was to identify the differences and changes in the curriculum to integrate myself into the UK curriculum, refining my teaching skills and methodology and to really embrace life in a school.

As a young student, I lost my enthusiasm for learning and had no real intentions to go to university. I did apply under duress from my parents and then went travelling on a gap year. On returning from my travels and with renewed focus, I went to university quite nervously. I managed to do really well in my Physics studies and achieved a first class grade. My confidence and belief in my abilities grew, but I had no interest to pursue a career relating to Physics as it had started to become an intimidating burden that I thought I knew.

Upon leaving university, I have completed an English teaching course and I worked in a summer school teaching English to European students and then travelled to China to teach English at an International School. After my first term, I was given the opportunity to teach secondary Physics. I believe this was the time when I started to really improve my Physics subject knowledge. Having to rediscover Physics concepts, breaking them down into manageable topics, taking into account language and cultural barriers and misconceptions, helped me to rediscover this subject. Initially, I had to play with several java applets to really get a good understanding of how to explain Physics concepts. The applets became essential, not only for concepts understanding, but also as a practical teaching method.

While progressing to advanced Physics levels, I found content that proved very tricky, or that I was not entirely familiar with. I often referred to mechanics textbooks to provide problems and consolidate knowledge. I was also able to discuss Physics

topics with a teacher from a Canadian program and some Chinese Physics teachers and I have spent extra learning time ensuring that I have understood the definitions and concepts. From my school experience, I remember not understanding electricity at all, only adding numbers into equations and hoping that they came out correctly. I sat down and learned how to define all the units and what they meant using different models.

On the PGCE course, I immediately became aware that my previous experiences would not be enough to teach secondary students. One area where I had no previous knowledge was learning theories of how students acquire knowledge. The knowledge of the learning theories has helped me to adjust the way in which I set up tasks and to allow students to discover much of the knowledge themselves. In addition, I have benefited greatly from the reflective practice. To allow time to assess the strengths and weaknesses of a lesson or allow students to reflect on what they have learned is a vital tool that has informed a lot of my work this year but is something that I would not have done otherwise. Another key process that helps me to check and identify weaknesses in my subject knowledge is metacognition. By focusing on how people learn and think and then linking this to the theories and reflection, my planning has become a lot more efficient and full of purpose.

One area that I had identified as requiring immediate improvement was practical work. In the university SKE sessions, we focused on small-scale practical work that could highlight key concepts and correct misconceptions. They do not require much equipment and could be easily set up and integrated into a lesson without much difficulty. The focus was on what the students would learn from practical work, as well as the logistical aspects of how to set up the equipment and use it.

From my perspective, perhaps the most interesting aspect of my SKE is that I took the greatest gains from the teaching rather than my education. In fact, the school and undergraduate experiences deterred me from doing Physics, but teaching brought me back and helped me to rediscover my confidence and passion in it. Most importantly though, it gave me an insight into which topics interest students; which topics students struggle with; and how to help students who lack a strong conceptual understanding. My subject knowledge has improved greatly during the PGCE course, but this would not have been possible without a solid base of experiencing a similar syllabus and cross-curricular links.

Student B - Subject knowledge versus pedagogy: which is more challenging?

My SK experience before entering the PGCE course, as a mature student, was a little different to those of my peers on the course. After gaining a degree in Astrophysics and a PhD in Quantum Chemistry, I have spent most of the following twenty-five years in education, with the longest periods spent in Higher Education as a senior lecturer and researcher. Like student A, I also had the opportunity to work outside the UK and I spent about ten years in Australia, Germany and Poland as a qualified freelance English teacher. In the year prior to entering the PGCE, I also gained useful experience in school teaching as a science supply teacher, and have

taken on a number of private tutoring in secondary Chemistry and Physics. I was therefore entering the PGCE in Physics and Mathematics from a position where much of the required subject knowledge, at least in Physics, was fresh and thoroughly ingrained due to both tutoring and having applied this knowledge every day as a professional scientist.

I found that a good place to start the audit of subject knowledge was to make detailed comparison of the syllabuses in Physics and Mathematics. The biggest change, since my secondary and university studies, is the modularisation of Mathematics, which now includes units such as Statistics and Decision Mathematics. While my research has frequently employed some areas of Statistics, there are some areas, such as significance testing and time series analysis, which I have never used. I have found it to be necessary and useful to study several Statistics and Decision Mathematics textbooks, together with tackling many of the sample problems posed in the textbooks. In my final placement, I have also been teaching many advanced and further Mathematics revision sessions in preparation for the examinations. Going through past papers in advance of the lesson, has been an essential preparation for the teaching and has served the dual purpose of refreshing my own subject knowledge in these areas.

The Advanced Physics do not differ hugely in content since my studies; however, a significant change is the downgrading of electronics and engineering topics in favour of quantum and elementary particle Physics. Having done no particle Physics since my degree, I found it necessary to refresh the basics of particle Physics, Feynman diagrams and special relativity using a combination of textbooks and various freely accessible websites.

When it came to Physics and Maths examinations, typically taken at the age of 16, I must admit that I had not expected to need much SKE for Mathematics, nor for Physics. However, there have been some big changes at this level since I took my exams in 1981. Perhaps, in an attempt to engage pupils more, the Science examination now is much more ambitious in its scope than the previous one. It demands that pupils learn a lot of information about a wide range of topics, including some that I never covered in my own education, such as geology, global warming and ozone depletion. Hence, even here I have found it necessary to learn some new material. Initially, I turned to the same textbooks that the students use. While these are aimed at pupil revision, from the teacher's perspective they are also provide very useful summaries of the syllabus in a very compact space. Moreover, like my colleagues, I have found the university SKE sessions to be very useful. I compiled these materials, together with my own individual notes and attempts at problems, in a sizeable folder. I found the sessions that focussed on teaching pedagogy in both Physics and Mathematics extremely useful, even revelatory.

In teaching, subject knowledge is often defined in a wider context to include knowledge of how the subject is taught, as distinct from an academic understanding of the subject matter. From my own perspective, acquiring and developing the pedagogical curriculum knowledge (PCK) has been a great challenge in the PGCE. Grossman (1990) defined a four-part model of PCK as to include subject specific

matter; an appreciation of pupils' common misconceptions; an appreciation of the curriculum; and knowledge of appropriate pedagogical techniques. Especially in Mathematics, I have found it difficult to get used to the patient, constructivist pedagogical approach that is now expected to be applied in order to engage and motivate the pupils. Fortunately, in my final school placement I have had the opportunity to teach mostly Advanced Mathematics and to be mentored by an outstanding young teacher. With his help, I have been making good progress in developing this key area of my teaching.

Student C - My route to becoming a Physics and Mathematics Teacher

Although my decision to pursue a career in Physics with Maths teaching was formally made in January 2014 when I accepted a PGCE place at university, the groundwork leading to that decision began during my school studies. It has been a long learning journey, which was filled with both highs and lows that have all contributed to my current subject knowledge.

My first experience of Physics came from my time spent in the Scottish education system. I made the decision to study Physics as it was a subject, which had not only captured my imagination but also, one in which I was achieving relatively high grades in during my lower years. Physics was my first real experience of a subject not coming to me naturally and, at the time, I struggled to admit that I needed help. This was a turning point in my attitude towards learning as I began to realise it would take more than just the work I completed in class to succeed. As a naive student, I could not see a use for the material outside of the school examination environment. Moving on from school education, I chose to study Motorsports Engineering at university. The whole university experience was a success, giving me the feeling of satisfaction and accomplishment, which deepened my desire to become a teacher after completing my degree.

However, before embarking on the PGCE course, I often found myself questioning whether I had made the correct decision. I knew from the beginning that it would be a mammoth challenge to transfer my engineering background to Physics with Mathematics teacher career, as there were large areas of Physics that I had not covered in detail since school. Before the course began, I purchased a set of textbooks and revision guides which I could use as the main resources to Physics and Mathematics knowledge in preparation for my lessons. I expected the work to be similar to that which I had completed in my own studies; however, I quickly realised this was not the case. Although there is some overlap between the Scottish and English syllabus, there were also very large differences. For example, the quantum Physics topic (OCR, 2013) is not covered in the Scottish Higher syllabus. This led to me starting the course in September with a feeling that I would have a lot of work in front of me to get up to the required standards.

Since joining the PGCE course, I have been able to continue my SKE in both Physics and Mathematics. The learning process starts with subject specific sessions during university scheduled days, where we are often presented with theory, examples and through provoking ideas. We are then encouraged to continue our

research at home. One of the biggest changes I have had to make, in order to progress as a student teacher, was to understand the curriculum and examination boards in England. Throughout my school placements, I have had the opportunity to work with different exam boards and I have been carrying out my SKE and research with regards to content in order to satisfy the course requirements. As part of my action plan for SKE, I have been revisiting different Physics course, in order to refresh my previous studies and understand how students may approach their learning. This was a plan which allowed me to revisit areas of the course, starting with the topics in which I have little experience or in which I had weaker subject knowledge and boost my confidence in teaching Physics.

As a trainee student at university, I have also been given the opportunity to attend SKE sessions in Mathematics and ICT. Learning how to use various programmes and software allowed me to create useful tests for students and to monitor their responses in real time. The great benefit from this approach, according to Clements's study (2000) was getting immediate feedback when students are trying out new techniques and ideas and exploring Physics and Mathematics problems in different ways. This has been a positive aspect of my subject knowledge enhancement at university, which I shall take into my future teaching career.

Looking back on all the university sessions, there are important points to consider and use in my future teaching career, the use of ICT, student's attitudes to learning and being encouraged to engage with metacognition and make more cross-curricular links. Participating in these sessions has encouraged me to continue my learning outside of the university classroom through reading key texts and attending development sessions within my placement schools, where appropriate.

Student D - Subject knowledge and growth in confidence

Nearing the completion of my PGCE in Physics with Maths, I now feel confident that my subject knowledge meets the standards required to teach in a secondary school. This, however, was not always the case. My confidence was left in tatters following my middle range degree result. I regarded this as a great academic failure. As I began the PGCE, my confidence in Physics subject knowledge was lower than ever, as I feared that I would no longer remember even what I had studied during my degree and due to the fact that I spent four years before beginning my PGCE course on an entirely unrelated field to Physics. My apprehension increased further as I read Green and Leask (2013) and my content knowledge was likely to be the area of the greatest confidence at the beginning of my teaching career.

At the beginning of the PGCE course, I was determined to improve my subject knowledge. I began reading through revision guides and past exam papers. I found that secondary Physics syllabus appeared to have changed more than the Mathematics syllabus since I sat my secondary school exams. Therefore, I found there were certain factual questions that I was simply unable to answer, whereas in Mathematics I was generally able to reason my way to the answer. The situation was different at Advanced Mathematics where I found the subject knowledge more

difficult. I had apparently retained more high-level subject content in Physics than in Mathematics due to my degree studies in Physics.

Despite this encouragement, I quickly realised that the subject knowledge required for teaching would be greater than I had anticipated. I had chosen to begin improving my subject knowledge by revising higher-level content because I wrongly assumed that if I mastered that, I would, as a by-product, also master lower level content. However, through the university-based courses, I began to see that teaching younger pupils lower level content is, in some respects, the most difficult kind of teaching as it requires explanations of content that appears obvious to oneself , e.g., 'multiplicative reasoning' in Mathematics. However, in general, I recognised that my subject knowledge base required expansion. This recognition was then underlined in my first school placement. I was required to teach Statistics, which involved teaching content that I had never been taught myself. Preparing to teach these lessons proved extremely time-consuming for me. My school subject mentor was aware of my difficulties and concluded that I needed to work hard to meet the expected standards for subject knowledge. During the Christmas holiday I therefore attempted to work through a series of Physics misconceptions; making links with higher level content.

In my second placement, I was the only physicist in the science department and I experienced significant pressure to have secure subject knowledge. When I was introduced in a staff meeting, I felt like a rare and valuable commodity in the school that wasted no time in taking advantage of my supposed "expertise". In my first week, without any warning, I was thrust before final year secondary students for a 'Physics intervention'. Having had little experience of teaching Physics at this level, I found this challenging. However, as the term continued, I was given the opportunity to teach more advanced Physics to more able secondary students and as I did so, my subject knowledge improved. I revised my subject knowledge using various resources for secondary Physics, such as BBC bitesize website, Institute of Physics website and revision guides. To ensure that I had sufficient knowledge, on occasion, I had consulted my degree notes and first year textbook (Tipler & Mosca, 2007). In general, most of my learning of subject content has been undertaken in this way - shortly before I have had to teach it. It seems as though this necessity to learn-in-order-to-teach coupled with perceived pressure from colleagues has driven me to more extensive subject knowledge. Pleasingly, by the end of the second placement my school mentor concluded that I had met the subject knowledge standards required to teach.

In conclusion, I have now successfully met the necessary standard required to teach. I owe this development to staff at both university and school that initially helped me see the great extent of the subject knowledge that I would need to acquire and with their high expectations of my subject knowledge. Their support and feedback have allowed me to teach the secondary Physics classes, which motivated me to work hard at improving my subject knowledge.

Discussion

The experiences and circumstances of the four secondary trainee teachers prior to entering the PGCE course have had a strong influence on their approaches to enhance their Physics and Mathematics knowledge. Students' subject knowledge enhancement is strongly connected with other forms of knowledge (Schulman, 1986) which have evolved throughout their initial teacher training. Based on student teachers' reflective accounts, a change in their attitudes and beliefs regarding their subject or pedagogical knowledge was the result of metacognition and reflections in response to new curriculum, conditions and objectives of teaching and learning. Their formal subject qualifications were insufficient for them to use their knowledge directly, but 'rather an intermediate knowledge which has already been reformulated' (Tiberghien et al., 1998:6). During their training, they have embraced different strategies to enhance their subject knowledge, e.g., using textbooks and technology, discussing with colleagues, learning about new forms of knowledge. At the end of their PGCE all four candidates report perceived success of their SKE strategies and feel that, with the help of the university-based training, they have met the standard with regard to this important aspect of ITT. With regard to the Physics and Mathematics SKE sessions provided as part of the PGCE course, these sessions helped them all to acquire and extend the different forms of knowledge.

Conclusions

One of the objectives of this study was to engage trainee teachers in academic research and writing. The authors were interested to express their experiences and views concerning subject knowledge acquisition and development, rather than seeing them as a group of students to be researched. Despite a heavy workload PGCE course, being part of this project has increase their motivation, skills, and knowledge required to engage constructively in a research and writing process.

Based on student teachers' reflective accounts, a change in their attitudes, beliefs and confidence regarding their subject knowledge took place during their initial teacher training at university. The synergy between subject, content, practical, technological and pedagogical knowledges is equally important during their university training courses and private study and it will be essential for the transition from a novice teacher to an expert. This research study provides some insights into trainee teachers' orientations and strategies toward the development of Physics and Mathematics matter knowledge, alongside other forms of knowledge.

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